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THE MINERAL COMPOSITION OF SOME SANDS FROM QUEBEC, LABRADOR AND GREENLAND

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RESULTS OF THE
RAWSON-MACMILLAN SUB-ARCTIC EXPEDITION OF 1926

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THE MINERAL COMPOSITION OF SOME SANDS FROM LABRADOR, QUEBEC AND GREENLAND

BY JAMES H. C. MARTENS

Rawson-MacMillan Expedition of the Field Museum of Natural History, 1926

In this paper are given the results of microscopic mineralogical analyses of some twenty samples of sand collected by the writer in part in northern Quebec in 1924, and in part in Labrador and Greenland from June to September, 1926, while with the Rawson-MacMillan Expedition.

The mineral composition of a sand reflects to some extent the character of the rocks from which it was derived, and also is in part determined by the processes by which the parent rocks were disintegrated, and the sand grains transported, sorted and deposited. Therefore, in connection with the descriptions which follow, brief mention is made of the types of deposit represented, and as far as possible the bed-rock source from which the sand grains came. As an explanation of the inclusion here of such widely separated localities, it may be said that all of the regions are alike in having been glaciated in Pleistocene or Recent time and in having a cold-temperate or arctic climate at present. Moreover, all of the sands, with the exception of that from Disco Island, are derived almost entirely from Pre-Cambrian crystalline rocks.

Sediments whose texture makes petrographic study easy were purposely selected, and for this reason beaches figure most largely among the types of occurrence. Some of these beaches are on lakes and others are on protected narrow bays where the wave action is moderate, corresponding to that in small lakes. None of these beaches faces the open sea, and the coast lines of Labrador and Greenland are such that beaches do not occur in exposed situations.

LABORATORY PROCEDURE

The laboratory work was carried out at Cornell University. The sand was first separated into a light and a heavy portion by means of bromoform of specific gravity 2.86. After drying the separated fractions, the percentage of heavy minerals was determined by weighing. On account of the practical absence of clay, preliminary washing could be omitted in most cases and the amount of clay removed was in no case enough to be of any significance.

Counting of grains was adopted as the best practicable method of arriving at figures for the relative abundance of the minerals making up each of the two fractions into which the samples had been separated. Therefore the percentage of grains heavier than 2.86 specific gravity is by *weight*, referred to the whole sample, while the percentage mineral composition of the heavy or light separate itself is by *number* of grains, so that without additional information figures can not be obtained giving the percentage on individual minerals referred to the whole sample, by either weight or number.

For counting the heavy mineral grains, methylene iodide ($n = 1.739$) and monobromnaphthalene ($n = 1.658$) were used as immerson media, while for the light portion, clove oil ($n = 1.532$) was found to be most convenient. Etching a short time and treating with dyes, as recommended by Johannsen and Merritt[1] for crushed rocks was found to be of some help in distinguishing the light minerals, but where several varieties of plagioclase are present and many of the grains are untwinned, some errors in the quartz and plagioclase seem to be unavoidable, since it would take far too long to test the interference figure of each grain. The potash feldspars are easily distinguished from quartz and plagioclase by their lower refractive index.

In the case of the heavy separate, care is necessary to get a representative part of it in preparing the slides for microscopic examination, since it would often be impracticable to count all of the grains, and it might also be desirable to save some of them unmounted. Difference in specific gravity, and in size and shape of grains, usually tends to keep the mixture of heavy minerals from being homogeneous. Dipping out the grains with a small spoon or spatula seems to be more reliable than pouring them out of the container.

Two methods of doing the actual counting are:—Firstly, to count all the grains of each mineral which touch the cross-hair intersection as the slide is moved slowly along successive parallel and

[1]A. Johannsen and C. A. Merritt, The recognition of minerals and the determination of their proportions in crushed rocks. Journ. of Geol. Vol. 34, pp. 462-465, 1926.

evenly spaced lines by means of the mechanical stage; secondly, to count all of the grains of each mineral in each of several successive fields which cover most of the area of the slide, but are so arranged as not to overlap. The first method is reliable only when the grains of the different minerals are graded in the same way as to size, or when all the grains are of the same size. It would be the easiest and most accurate method to use in case we were dealing with fractions of nearly uniform size separated by sieving. The second method is the one used by the writer for all the counts for which figures are given in this paper. It has been discussed in detail by Salmojraghi,[1] one of the few workers in sedimentary petrography who have published quantitative, microscopic, mineralogical analyses of sands. His figures, showing the effect on the accuracy of the results of the number of grains counted, have been corroborated in a general way in the course of the present investigation.

Because of the types of deposits sampled and the climatic conditions prevailing, nearly all of the grains were unweathered and free from coatings which would hinder identification. Small percentages of altered grains were usually classed with what appeared to be the original mineral, while the number of grains in any of the sands which had to be classed as "unknown" or "doubtful" was so small as to be negligible. Since the minerals present, with the exception of the zeolites in the sand from Godhavn, are all known to be common in sediments, and since no question of correlation or exact source is involved, it seems safe to omit detailed descriptions of minerals. It may be remarked, however, that many different varieties of the same mineral are in some cases present in the same sand; this is particularly true of the pyroxenes, amphiboles and garnets. For convenience, all of the monoclinic pyroxene is listed as augite. Diopside and titaniferous augite were not observed, although it is quite possible that they are present in small amount.

Explanation is needed for the term "black-opaque" as used here. Under this heading are included as far as possible only minerals which have a metallic luster, and are therefore truly opaque. Rarely, grains of dark hornblende of unusual shape may have been included here, but ordinarily characteristic cleavage and translucence on thin edges will distinguish even the larger grains. The principal metallic minerals in these sands, as in most others, are undoubtedly

[1]F. Salmojraghi, Atti. Soc. Ital. Sci. Nat. XLIII, pp. 54-89, 1904.

magnetite and ilmenite; others whose presence here is highly probable but not proven are chromite and specular hematite. That allanite should be entirely absent seems scarcely possible, in view of its observed occurrences in bed-rock near where some of the samples were collected, and small amounts of this mineral may, on account of its dark color, have erroneously been included with the black-opaque grains.

Much better checks were obtained in counts of successive slides of the heavy than of the light minerals, in spite of the greater number of heavy minerals and their tendency not to stay uniformly mixed. The explanation of this lies in the difficulty, already referred to, of distinguishing the quartz from the plagioclase with both speed and accuracy. On this account perhaps some of the figures for the light minerals are as much as ten per cent in error.

In addition to the minerals listed in the table, about half a dozen others were noted as occurring very sparingly in one or two samples each, and one sample is so different from the others that it is described in the text but not included in the table of grain counts.

DESCRIPTION OF INDIVIDUAL SANDS

QUEBEC

No. 1. Pleistocene Marine Sand from Ile d'Alma, Lake St. John County, Quebec. This was collected from a pit where great amounts of sand had been excavated for use in the construction of the dam and power house at Ile Maligne on the Saguenay River. It was deposited in Post-Glacial time when the land was much lower than it is at present, the elevation above sea level at this locality now being about 275 feet. The surrounding country is a part of the great Saguenay anorthosite[1] mass, although other rocks, especially granite and various gneisses and amphibolites, are present in noteworthy amount.

Since there were no variations in color of the sand in the bank to indicate local concentrations of heavy minerals, it seems likely that ten per cent of heavy minerals, as shown by the analysis, is about the normal amount for this deposit. No actual measurements were made on the light portion, but it consists of quartz, plagioclase and potash feldspars, in what are estimated to be approximately equal amounts.

[1]F. D. Adams, Neues Jahrb. Beilagebd. VIII, p. 434.

Nos. 2 and 3, Beach Sand from Cronick Lake, Damville Township, Lake St. John County, Quebec. Both of these samples were collected from the beach on the east side of the lake in August, 1924, and represent nearly pure, heavy concentrates formed by the lapping of the waves. These dark, heavy sands occur as thin strips parallel to the shore and are accompanied by a much greater amount of light yellow sand consisting of quartz and feldspar. Sample No. 2 was collected near the outlet of the lake, and No. 3 two miles to the north, or about half-way between the inlet and the outlet, but there is nothing to suggest an essentially different source to explain the difference in composition shown by the grain counts. Both are derived from glacial deposits in the valley of the Miloasas River, which flows through the lake, and of which the lake itself is simply an expansion. The bed rocks as far as known are principally granite and various gneisses and amphibolites in which garnet is a common constituent.

The difference in the percentages of *garnet* and of *black-opaque* grains in the two samples is especially noteworthy; the sand with more black-opaque grains and less garnet has also a much finer texture, as shown by the sieve analyses which Prof. Ries, of Cornell University, very kindly had made for the writer.

SIEVE ANALYSES OF SANDS FROM LAKE CRONICK, QUEBEC

Retained on sieve No.	*Sample No. 2*	*Sample No. 3*
40	.83	.13
70	85.13	4.69
100	13.74	67.21
140	.13	23.78
200	tr.	3.51
270	—	.45
Pan	.02	.04

The difference in texture of these two sands seems to the writer to be directly related to the difference in mineral composition. This idea is supported by the usual occurrence of garnet in far larger grains than magnetite and ilmenite in the bed rocks of the region, and also by the fact that in more poorly sorted sands derived from areas of metamorphic rocks, the grains of garnet are often much larger than those of magnetite and ilmenite. That zircon is four times more abundant in the finer sand is not surprising when we recall the usually small size of zircon crystals in igneous and metamorphic rocks.

Nos. 4 and 5. Beach Sand, Lac Brochet, Damville Township, Lake St. John County, Quebec. These are both from the sand beach on the northeast shore of Lac Brochet, otherwise known as Stacker Lake; one represents a dark, reddish, heavy concentrate formed by wave action, and occurring in narrow strips along the shore, while the other is a sample of the ordinary, light-colored sand containing about an average amount of heavy minerals. Directly back of the beach is a sand plain composed of water-transported, glacially-eroded material, from which the beach sand is derived. It is interesting to note the close agreement in composition between samples Nos. 2 and 4, which were collected five miles apart, and are similar in texture as well as in origin.

Comparison of the mineral composition of these two samples from the same locality shows how different minerals are affected by the process of wave sorting. The enrichment by the oscillatory action of the waves applies especially to the garnet and black-opaque minerals, since, in the sand with the larger proportion of heavy minerals, they make up a far greater proportion of the heavy fraction than they do in one with a smaller proportion of heavy minerals. On account of their intermediate specific gravity, and the flat shape of many of the grains, the hornblende and pyroxenes are not concentrated to anything like the same extent as the black-opaque minerals and garnet.

No. 6. Alluvial Sand, Ashuapmuchuan River, Damville Township, Lake St. John County, Quebec. This sample represents a heavy concentrate produced under somewhat different conditions than those just discussed, in that the sorting is not effected by waves caused by wind, but rather by the waves and surges of a heavy rapid in the river. The channel of the river at the rapid is in bed-rock and the current is too swift to allow permanent deposition of sediment, but an indentation in the shore has given the opportunity for the formation of a small sandbeach and the sorting out of strips of the heavy minerals on it.

At the same locality the separation of biotite mica from sand was observed in a shallow pool which had no current passing directly through it, but had sufficient connection with the rapid water to make it subject to a continual slight agitation which caused the mica to rise to the surface of the sand.

LABRADOR

No. 7. Beach Sand, near mouth of Ugutuk River, on shore of bay about 30 miles inland from Hopedale, Labrador. This sample was collected by E. P. Wheeler, in the summer of 1926. The locality as given above is very approximate, since the Ugutuk River is not shown on maps or charts. The thoroughness of the sorting of the heavy minerals is shown by the large percentage of black-opaque grains. Igneous and metamorphic rocks of deep-seated origin are indicated as the principal sources of the sand grains.

No. 8. Pleistocene Delta Sand, Nain, Labrador. This sample was taken from a raised delta of a small stream a little less than a mile inland from the small bay on which the Mission of Nain is located. A bank, 30 feet high, of poorly sorted, stratified sand with some pebbles and boulders had been exposed by the erosive action of the stream, and the sample was collected from the middle portion of this bank at a height roughly estimated as 70 feet above sea-level. In making the bromoform separation and the grain counts, only that portion passing a 40 mesh sieve, which was 81 per cent of the whole, was used. Reference to the table gives some idea of the great complexity of mineral composition; doubtless other minerals are present in small amount and could have been detected by making additional separations or examining a greater number of grains. Anorthosite is the principal bed-rock of the immediate vicinity and the dust-speckled plagioclase as well as the pyroxenes and amphiboles may have been in large part derived from it. However, the abundance of boulders of granite and various gneisses, as well as the amounts of quartz, potash-feldspar and garnet in the sand itself, indicate derivation of much of the material by glacial transportation from the little known interior.

No. 9. Beach Sand, Nain, Labrador. Most of the shore near Nain is rocky, but for a short distance on the mainland south of the mission station, and not far from the mouth of the little stream mentioned in connection with the last described sand, there is a narrow sand beach. On it the action of the small waves in the bay has concentrated the heavy minerals, as shown by the fact that the sample contains 76 per cent of grains with specific gravity over 2.85. The original sources of the sand in the two deposits represented by samples Nos. 8 and 9 must be nearly the same, but the sorting action of the waves on the beach, which has locally caused a concentration of heavy minerals, has also effected changes in their relative proportions and made the texture more uniform.

No. 10. Beach Sand, Lady Bight, about latitude 57° 20′ on the Labrador Coast. The harbor known as Lady Bight, on the shore of which this sample was taken, is on one of the inner islands not shown on the nautical chart. The sand occurs only in hollows in the rocks, not forming any continuous beach, and were it not for the sheltered situation it would have been washed away entirely. In the comparatively large per cent of titanite among the heavy minerals this sand shows a marked difference from the others examined. Fortunately there was an opportunity of examining the bed-rock of this island and it was found to consist of granite in which titanite is present in such amount and size as to be plainly visible without the aid of a microscope. It is therefore likely that the composition of the sand is strongly influenced by the local rocks, rather than that some unusual process of sorting or weathering has been at work. Glacial boulders other than those of the island itself show that some material must also have been derived from the mainland.

No. 11. Beach Sand, Port Manvers, Labrador. This sample was collected from the beach on the peninsula leading out to Thalia Point, which forms one side of the harbor of Port Manvers. It consists of worked-over morainic material, together with the products of the disintegration in place of a coarse olivine gabbro which is the bed rock. Since the specimen contains only two per cent of heavy minerals, it seems likely that it represents sand with far less than the average amount of heavy minerals for the locality, and the small amount of black-opaque grains in the heavy portion also suggests that some of the heavy minerals may have been removed by wave sorting. No observations bearing on this were noted at the time of collection. The grain counts show to what extent plagioclase feldspar, hypersthene, and olivine, none of which are extremely resistant to weathering, may be present in a sand. The glacial derivation of much of the material and the severe climatic conditions of the present day account for the small degree of alteration.

No. 12. Beach Sand, Saglek Bay, Labrador. This sample was taken four feet below high-tide level on the shore of a small bay on the south side of Saglek Bay and five miles west of its mouth. As far as seen, the rocks near by are gneisses with bands and lenses of amphibolite, veins of quartz and pegmatite, and dikes of diabase, but, as usual at low elevations in Labrador, a large part of the sand may be derived from glacial deposits.

GREENLAND

Nos. 13, 14, 15, 16. Holstenborg, Greenland. The first two of these samples, taken from a small beach between two rock points on the north side of the little bay on which the harbor of Holstenborg is located, show the sorting out of the heavy minerals, and more particularly, the way in which the proportions of the various heavy minerals are changed as natural concentration takes place. Streaks of the dark, heavy sand (No. 13) extend along the beach at about the upper limit of wave action, and are associated with much greater amounts of light-yellow sand (No. 14). The grain counts show that the garnet and black-opaque grains (magnetite and ilmenite) are the minerals to be most effectively concentrated by the waves, while the pyroxenes are concentrated to a lesser extent, and the hornblende with slightly lower specific gravity and a tendency to flat or elongated shape, actually goes with the quartz and feldspar rather than with the heavier minerals.

Samples 15 and 16, collected from the shore of a small lake two miles east of Holstenborg, also owe their large content of heavy minerals to wave sorting. It will be noted that the sand with the larger weight percentage of heavy minerals has also the larger number of black-opaque grains relative to other minerals in the heavy portion. The appearance of the grains of the various minerals is practically the same as in the two preceding samples from the salt-water beach.

No. 17. Glacial Sand, Kugssuak, South Strom Fjord, Greenland. This ideal example of a glacial sand was collected from a hollow in the rocks on the side of Kugssuak (Big Brook), a glacial stream entering the south side of South Strom Fjord 35 miles above its mouth. The glacier is only a mile or two up the valley from the point where the sample was taken, and the current of the stream is so swift that one might expect coarse sand to be easily carried in suspension. The sand was evidently deposited as the stream fell from a higher to a lower stage. In color, the sand is light-gray, and has all the appearance of a crushed rock, which indeed it is; loose packing and lightness of the dry material resulting from the angular shape of the grains, were especially noted. Under the microscope the fresh, unweathered appearance of the grains of all the minerals is very striking, there being less evidence of weathering than in many specimens collected as representing fresh, unweathered, igneous rocks. Many of the grains show crystal faces, while the others show characteristic fractures and cleavages to an eminent degree, since the wear subsequent to the breaking up of the rock has been practically nothing.

To facilitate mineralogical study, which was made somewhat difficult by the poor sorting of the grains, the sample was sieved through bolting cloth with openings .08 mm. square. In this way a coarse fraction, amounting to 56 per cent, and a fine fraction of 44 per cent of the whole were obtained, these being designated as 17a and 17b respectively in the table and chart showing the grain counts. The heavy and light minerals in each of these fractions were separated in the usual way, and although the separation of heavy from light in the finer sizes was not absolutely complete, the percentages of heavy minerals, 22 for the coarser and 43 for the finer, may be taken as essentially correct. In the determination of the mineral composition it was found to be impossible to distinguish quartz from plagioclase accurately enough to make any grain counts on the finer, light portion. In addition to the minerals shown in the table, small amounts of pyrite, chalcopyrite, enstatite, and tremolite are also present.

Comparing the composition of the finer and coarser heavy portions of this sand, it is seen that the finer part is greatly enriched in heavy minerals, and that among the heavy minerals the proportion of hornblende and epidote is greater in the fine than in the coarse portion. Hornblende is less resistant to crushing and abrasion than quartz, feldspar or mica, as shown by the experimental work of Johannsen and Merritt,[1] and this probably accounts for the greater percentage of it in the fines. As shown by the occurrence of many distinct crystals both loose and as inclusions in feldspar, the epidote must have occurred in small crystals in the bed rock, and thus tended to be in small grains when the rock was broken up.

From the outcrops which were seen near by, and from the pebbles found in the same stream with the sand, it appears that the principal bed rocks of the region are amphibolites and gray gneisses. The practical absence of garnet and pyroxenes from the sand and the great scarcity of magnetite and ilmenite show that the region of its derivation must be much different from that of the sands collected in the vicinity of Holstenborg.

No. 18. Zeolitic Beach Sand, Godhavn, Disco Island, Greenland. This sand was collected at about high tide level on a small beach in the harbor of Godhavn. The bedrock immediately below is banded granitic gneiss, but scarcely half a mile to the north there

[1]A. Johannsen and C. A. Merritt, Comparative losses in crushing and sifting rock minerals. Journ. of Geol. Vol. 34, pp. 275-280, 1926.

are high cliffs of basalt and other volcanic rocks, including some tuffs, and the talus at the foot of these reaches nearly to the shore. The proportion of compound grains of fine-textured and much altered volcanic rocks is so great that separation by heavy liquids is of little value except in isolating the zeolites for study. The estimated composition by number of grains is as follows:

Compound grains	65 per cent
Quartz	10 per cent
Zeolites	10 per cent
Potash feldspar	3 per cent
Augite, olivine and hornblende	2 per cent

On account of the presence of abundant yellow and red stains of iron oxide, more detailed classification of the compound grains is not practicable. Among the zeolites found were natrolite, chabazite, stilbite, and probably apophyllite. From the abundance of zeolites in both the massive and tuffaceous varieties of the basalt, the presence of these minerals in the sand such a short distance removed is not surprising. Even the grains of such comparatively soft minerals as the zeolites show little evidence of wear, and have approximately the same appearance as fragments produced by crushing large crystals or aggregates. For this reason it does not seem necessary to give detailed descriptions, even though these minerals are little known as constituents of sediments.

Quartz, microcline, and a very small amount of green hornblende are the only minerals in this sand which appear to have come from the gneisses rather than the basalts.

No. 19. Lake Beach Sand, Egedesminde, Greenland. The lake on the shore of which this sample was taken is a very small one on the island of Egedesminde, which is across Disco Bay to the south of Godhavn. Egedesminde and the island near it are rather low and show strongly glaciated surfaces of granite and granitic gneiss. The composition of the heavy fraction is shown in the table and chart Pl. IX, while the light portion is the usual combination of quartz, potash-feldspar and plagioclase, with a small proportion of diatoms in addition.

No. 20. Eolian Sand, Agpamiut, near Sukkertoppen, Greenland. This sand is derived from a stratified moraine or perhaps a raised delta, but on the surface where the sample was collected it has been reassorted by wind action, and may therefore be classed as of eolian origin. Grain counts of the heavy minerals were not made, but qualitative examination shows this sand to be very similar to sample No. 14, from Holstenborg.

RESULTS AND CONCLUSIONS

As a result of careful examination of twenty samples it is concluded that satisfactory quantitative determinations of the mineral composition of sand can be made by counting under the microscope the grains of each mineral in properly representative slides. Such counting is much more laborious than qualitative estimates of abundance, especially when the number of minerals present is large, but it is believed that in many cases the results may be correspondingly more instructive. Moreover, it will often happen that in the examination of the individual grains necessary to counting them, one or more minerals are found which otherwise would have been overlooked.

With regard to the particular sands included in this investigation a number of conclusions may be reached from a consideration of the mineral percentages, taken together with the other information available.

Attention may be called first to the relation of the kind of bed rock to the mineral composition of the sand. It is seen that the local rock has a notable effect on variations in mineral composition, even in regions where there has been much glaciation. This is shown especially by the olivine in the sand (No. 11) from Port Manvers, and the titanite in the sand (No. 10) from Lady Bight, Labrador. In both of these instances it is highly probable that a part of the contribution of local material is the result of post-glacial weathering.

The large percentage of feldspar found in the light portions of all the samples is quite as one would expect from the known facts as to climatic conditions and the kind of rocks from which the sand grains were derived; it is quite in accordance with the descriptions of sands in glaciated regions elsewhere. However, an excess of plagioclase over potash feldspar, such as is shown by samples 8, 11, 12, 14, 16, 17, and 20, is not generally recognized as being a common thing in sediments. It seems probable that it is due to the presence of large amounts of such rocks as anorthosite, gabbro, amphibolite, and plagioclase gneisses, so that there was actually a greater supply of plagioclase than of potash feldspar. Clark and

Washington[1] gave in the norm computed from 99 analyses of igneous rocks in eastern Canada, including Newfoundland and Labrador, orthoclase 16.12, albite 41.39 and anorthite 14. 73 per cent. Granite and anorthosite, the commonest igneous rocks of the area in question, are by no means adequately represented by these analyses, while the rocks definitely recognized as metamorphic are not represented at all; moreover, the actual mineral composition may differ materially from the norm computed from the chemical analyses. At least these analyses are favorable to the idea of a greater supply of plagioclase than of potash feldspars. With the exception of almost pure albite, the plagioclases are more easily destroyed by weathering than the potash feldspars, but the sands under consideration were formed by the breaking up of rocks under conditions of severe frost or glaciation, where the opportunity for chemical weathering was slight. Under warmer conditions, it is probable that even with an abundant supply of plagioclase, enough of it would be weathered so that there would generally be less of it than of orthoclase.

The variety of minerals present is due in part to the conditions favoring escape from destruction by weathering, and in part also to the complexity of the bed-rock in the contributing areas. With regard to the kinds of heavy minerals present, it may be noted that there is commonly a preponderance of garnet, pyroxenes, amphibole, magnetite, and ilmenite. Such minerals as zircon, rutile, tourmaline, and leucoxene, which often make up most of the heavy fraction of sands derived from other sediments, or even from crystalline rocks under conditions favorable to chemical weathering, are here so diluted, or mixed with the more abundant minerals, as sometimes to be found only by long searching.

Two samples of sand of different coarseness derived from the same source, or the finer and coarser portions of the same sand, may show a wide difference of mineral composition, which is directly dependent upon the texture. Going farther back, the size of the grains of the various minerals in the sand is determined in part by the size of the crystals in the parent rock, and in part by the relative ease of breaking and wear as determined by cleavage, hardness, and brittleness. I have already suggested that the formation of heavy concentrates rich in garnet on the one hand, and in magnetite and ilmenite on the other, may be due in part to the difference in size of the grains of these minerals in the rocks from

[1]United States Geological Survey, Prof. Paper 127, p. 42.

which they were derived. The tendency of hornblende to become more finely divided than many of the other common minerals may increase its amount in the finer and decrease it in the coarser portions.

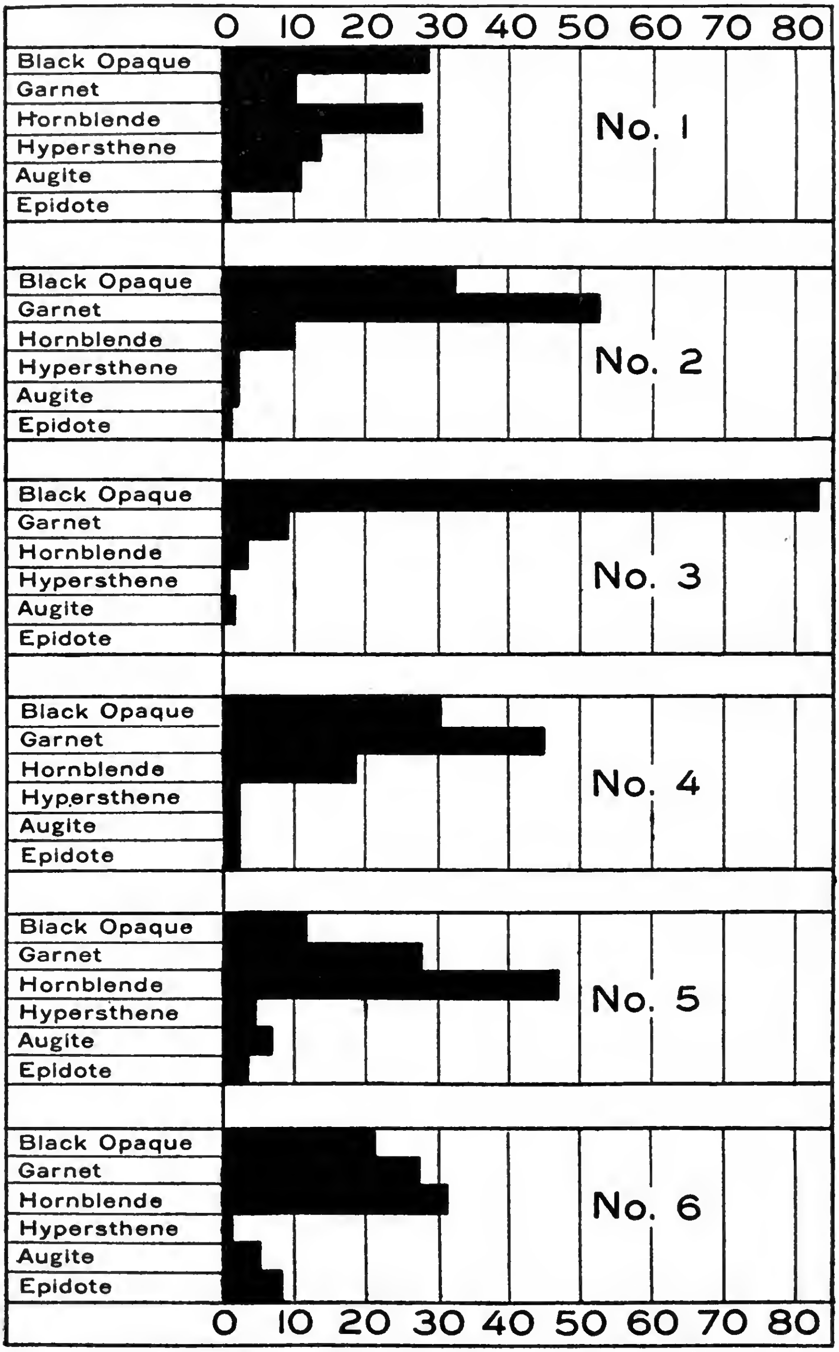
Regardless of the previous history of a sand, if it contains minerals of not too closely concordant specific gravities, it may, when subjected to wave action on a beach, be more or less perfectly sorted so that the heavy and light minerals will be in alternating streaks or lenses. Assuming the simple theoretical case of sorting into two portions only, the hornblende, on account of the intermediate specific gravity and somewhat flat shape of the grains, tends to associate with the quartz and feldspar, rather than with the heavier minerals. Micaceous minerals are for the most part carried from the scene of action out into the deeper water. The action of the waves in sorting out or panning the heavy minerals is a complicated process, to describe the details of which many more observations are needed.

Thus far all of the discussion in this study has been based on the examination of recent sediments whose origin is not excessively obscure. With increase in knowledge of the mineral composition of the present day sediments and the relation of the composition to the various factors influencing it, more and more generalizations can be established which will help in interpreting the older sediments. Although the mineralogical analysis of a few samples may in itself be of little value, yet, when all of the geological relations are considered, the presence or absence of certain detrital minerals or groups of minerals, and the relative proportions of the various minerals which are present, may constitute very decisive criteria in problems concerning ancient climates, sources of sediments, conditions of deposition, and correlation of formations.

MINERALOGICAL ANALYSES OF SANDS

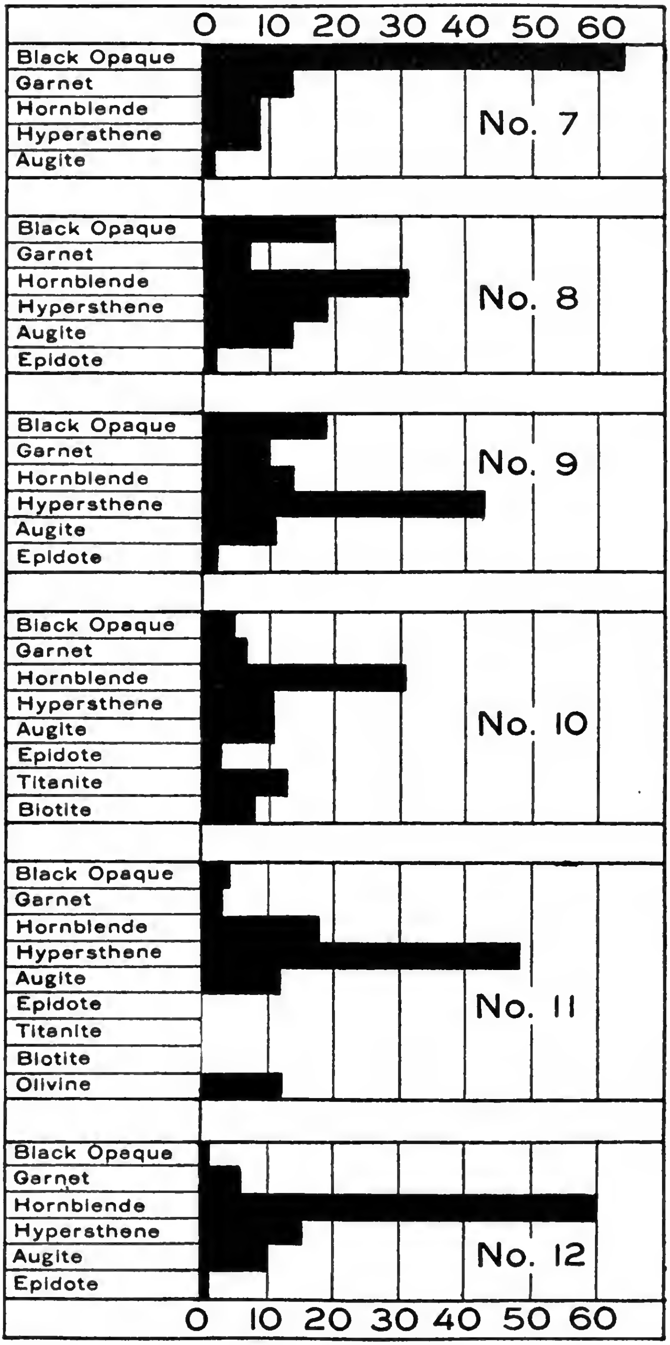
	QUEBEC						LABRADOR						GREENLAND							
Number of sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17a	17b	19	20
TOTAL NUMBER OF GRAINS COUNTED																				
Light	....	....	....	....	150	....	....	456	....	538	462	584	....	789	....	518	169	....	....	642
Heavy	1330	766	1214	1016	850	1313	735	432	461	330	854	821	1015	180	1176	620	548	514	342	....
Per cent by weight heavier than 2.86	10	98	97	78	12	88	97	11	76	4	2	10	98	15	97	56	22	43	4	18
LIGHT MINERALS — PER CENT BY NUMBER OF GRAINS																				
Quartz	....	....	....	....	73	....	....	58	....	48	23	52	....	52	....	54	46	....	....	51
Potash-feldspar	....	....	....	....	14	....	....	17	....	27	9	12	....	11	....	8	4	....	....	22
Plagioclase	....	....	....	....	13	....	....	25	....	25	68	34	....	37	....	38	50	....	....	27
HEAVY MINERALS																				
Black-opaque	29	32	83	30	11	21	64	20	19	5	4	1	48	4	70	36	0.2	0.6	0.5	....
Garnet	10	51	9	44	27	27	14	7	10	7	3	6	21	7	11	10	x	....	8	....
Hornblende	28	10	3	18	46	31	9	31	14	31	18	60	3	22	4	15	63	61	63	....
Hypersthene	14	2	0.5	2	4	1	9	19	43	11	48	15	14	25	9	20	....	....	4	....
Augite	11	2	1	2	6	5	2	14	11	11	12	10	13	39	5	17	....	....	3	....
Epidote	1	1	0.3	2	3	8	0.3	2	2	3	0.4	1	....	....	....	0.3	10	23	11	....
Titanite	1	0.4	0.4	0.8	0.8	2	0.1	0.2	....	13	0.1	0.1	....	....	0.3	0.2	0.4	1	2	....
Apatite	2	....	....	x	....	2	0.1	4	....	1	1	0.4	....	....	0.1	0.6	0.4	1	4	....
Zircon	3	0.8	3	0.4	0.4	1	1	0.7	0.2	0.6	0.1	0.1	0.5	0.5	0.8	0.3	....	x	2	....
Rutile	0.2	0.4	0.1	0.3	0.2	0.6	0.4	x	0.2	0.3	....	....	....	0.1	0.1	....	....	....	1	....
Biotite	x	....	....	....	....	....	....	0.2	....	8	....	1	....	2	....	....	21	12	....	....
Monazite	0.2	....	....	....	....	....	....	0.2	....	....	....	....	....	....	....	....	....	....	0.2	....
Sillimanite	....	....	....	....	0.1	0.3	....	0.5	....	0.3	0.8	2	....	....	....	....	....	....	0.2	....
Tourmaline	....	....	....	x	0.1	....	....	x	....	0.3	....	0.7	....	....	0.1	0.2	....	....	....	....
Actinolite	....	....	....	0.3	....	0.3	....	0.2	....	....	....	3	....	....	....	....	2	0.4	....	....
Olivine	....	....	....	....	....	....	....	....	....	....	12	0.5	....	....	....	....	....	....	....	....
Muscovite	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2	1	....	....
Altered Feldspar	0.5	0.7	....	....	....	0.7	....	....	....	8	....	....	....	....	....	....	....	....	....	....

X indicates presence of mineral in amounts so small that it did not appear in the fields counted



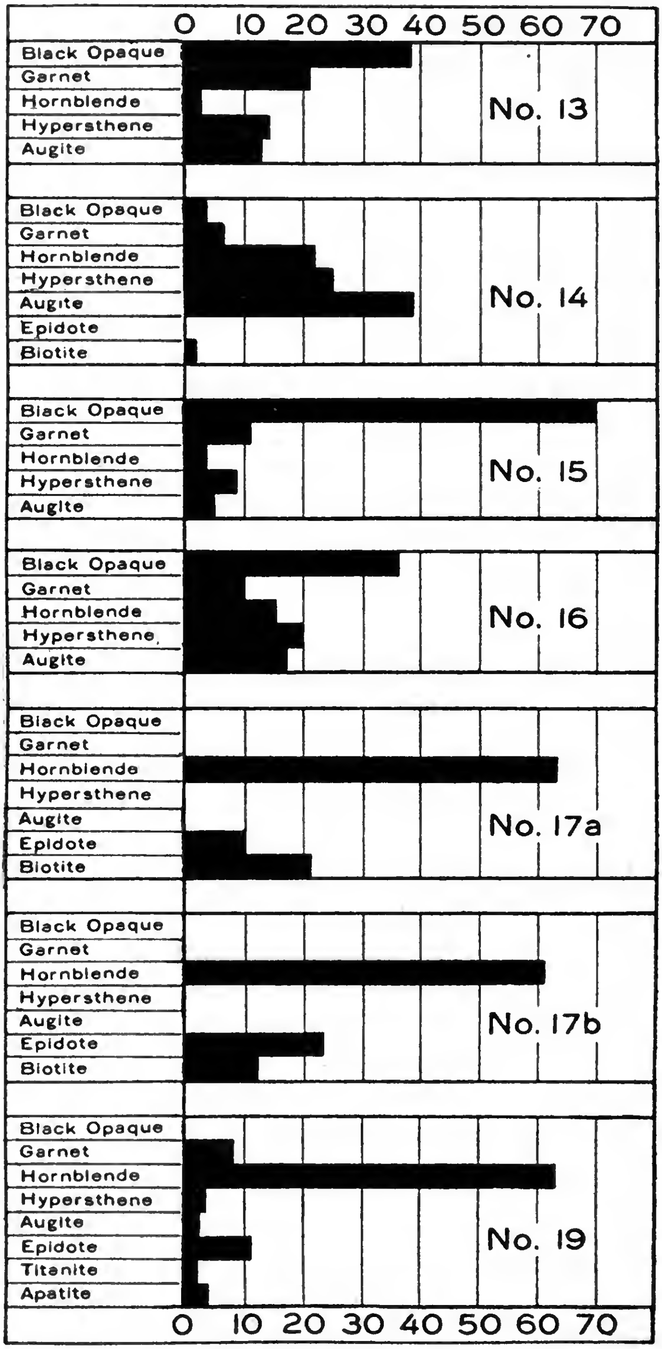
Graph showing principal heavy minerals in sands from Quebec

Per cent by number of grains in part of sand of specific gravity greater than 2.86



Graph showing heavy minerals in sands from Labrador

Per cent by number of grains in part of sand of specific gravity greater than 2.86



Graph showing heavy minerals in sands from Greenland

Per cent by number of grains in part of sand of specific gravity greater than 2.86